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STRENGTH OF FASTENERS IN PARALLEL-LAMINATED VENEER.(U)
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United States Department of Agriculture

Forest Service

Forest Products Laboratory

Research Paper FPL 389

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Strength of Fasteners in Parallel-Laminated Veneer

Abstract

An experimental study was conducted to investigate the strength of common fasteners in parallel laminated veneer (PLV). Phase I results indicated that the effects of lamina thickness and the degree of lathe checking could not be detected in either nail withdrawal or lateral loading. During Phase II PLV constructed from 3/16- and 4/10 inch Douglas-fir laminations was tested using staples, bolts, split rings, and truss plates. No severe reduction in the fastening strength of the PLV was detected (with the exception of 4/10 inch PLV with truss plates).

Acknowledgment

The authors wish to express their gratitude to Dr. Thomas L. Wilkinson of the Forest Products Laboratory for his assistance in this study.

United States Department of Agriculture

Forest Service

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Research Paper FPL 389

Strength of Fasteners in Parallel-Laminated Veneer

By
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Introduction

Although parallel laminated veneer (PLV) possesses many potential advantages through the dispersion of strength-reducing characteristics, earlier work *(3,7)*[2] has suggested that its fastening characteristics may be considerably reduced below those of solid sawn wood. This present study, performed in two phases, was designed to further explore the fastening characteristics of PLV. The first phase investigated the effects of lathe checking and veneer thickness on the nail joint strength of PLV; a second phase determined the joint strength of some of the other more commonly used fasteners with PLV and compared those values to ones obtained for solid wood.

PHASE I

The objective of this phase was to investigate the effects of lathe checking and veneer thickness on the withdrawal and lateral nail-holding ability of PLV. Tests were performed on products laminated from tightly checked veneer (veneer with a minimum of lathe checking), loosely checked veneer (veneer with severe lathe checking), and solid sawn lumber. Each of the above products was constructed from nominal ply thicknesses of 4/10, 1/4, and 1/8 inch to produce 1-1/2-inch laminated dimension stock. Table 1 lists each material group and its corresponding label. Withdrawal and lateral nail resistance tests were performed on each group. Veneer samples of each thickness were randomly selected and evaluated for the amount of lathe checking present.

Material and Specimen Preparations

The material used was Coast Douglas-fir. Most of the test material had no knots; a few knots less than 1/2 inch in diameter were allowed.

PLV

Five 4-foot-long veneer logs were rotary cut to obtain veneer thicknesses of 4/10-, 1/4-, and 1/8-inch. Prior to cutting the logs were heated to 140° F for at least 40 hours. Different lathe settings were utilized to obtain varying degrees of lathe checking (table 2). After cutting the veneer was press-dried at 50 pounds per square inch and 350° F to approximately 12 percent moisture content. All veneer was then randomized before the laminating process was initiated.

To laminate the PLV material, the 4/10- and 1/4-inch veneer was reheated to approximately 220° F in a roller dryer. A phenol resorcinol adhesive was applied at a spread rate of 60 pounds per 1,000 square feet of glueline. The veneers were arranged with their checked sides toward the center and 150 pounds per square inch pressure was applied for approximately 5 minutes.

To laminate the 1/8-inch veneer, a phenol resorcinol glue was applied with a hand roller at room conditions. The spread rate was not controlled. The assemblies were pressed at pressures of 150 to 200 pounds per square inch for 24 hours.

Solid-Sawn Laminated Lumber

The solid-sawn laminated material was constructed to resemble PLV, but without the lathe checking inherent to most knife cut veneer. Logs were sawn and ripped into strips that were approximately 4/10-, 1/4-, and 1/8-inch thick. Care was taken to keep all strips as close to flat grain as possible. The material was then press-

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Italicized numbers in parentheses refer to literature cited at end of report.

dried, randomized, and laminated by the same procedures as used for the 1/8-inch veneer.

After material preparations all specimens were stored at 80° F and 65 percent relative humidity until testing time.

Experimental Procedures

Measurement of Lathe Checking

To obtain a measure of the degree of lathe checking present in the veneer, approximately 10 percent of the tight and loose veneer of each thickness was randomly selected for evaluation. Samples were crosscut in half and the cross sections stained with india ink. A thin slice was removed with a jointer from the stained edge leaving the dyed checks visible. The 1/8-inch veneer was also scraped with a microtome knife to obtain a smoother surface and to aid in measurement of the lathe checks. The depth of the lathe checks were measured visually with the aid of a microscope to the nearest 0.016 inch. The frequency of lathe checks (checks/in.) was also recorded.

Nail Withdrawal Tests

Eightpenny common wire nails, typically 2-1/2 inches long and 0.131 inch in diameter, were driven perpendicular to the glueline to a depth of 1-1/4 inches. The nails were alined perpendicular to the face by sight and a steel shim used to obtain the proper depth of penetration. The nails were given a 15-minute bath in methyl alcohol before testing to remove any coating or surface film that may have been present as a result of manufacturing operations. Withdrawal tests were conducted immediately after the nail was driven. Each nail was used only once.

The method for withdrawing the nails is shown in figure 1. The procedure followed that outlined in ASTM D 1761 *(1)*. All tests were conducted at a constant machine head speed of 0.1 inch per minute. The nail withdrawal was measured by the movement of the machine head with respect to the face of the specimen. A linear voltage differential transducer (LVDT) was used for measurement and load-withdrawal curves were recorded on an X-Y plotter. Maximum withdrawal loads were also recorded. Thirty tests were performed on each material group.

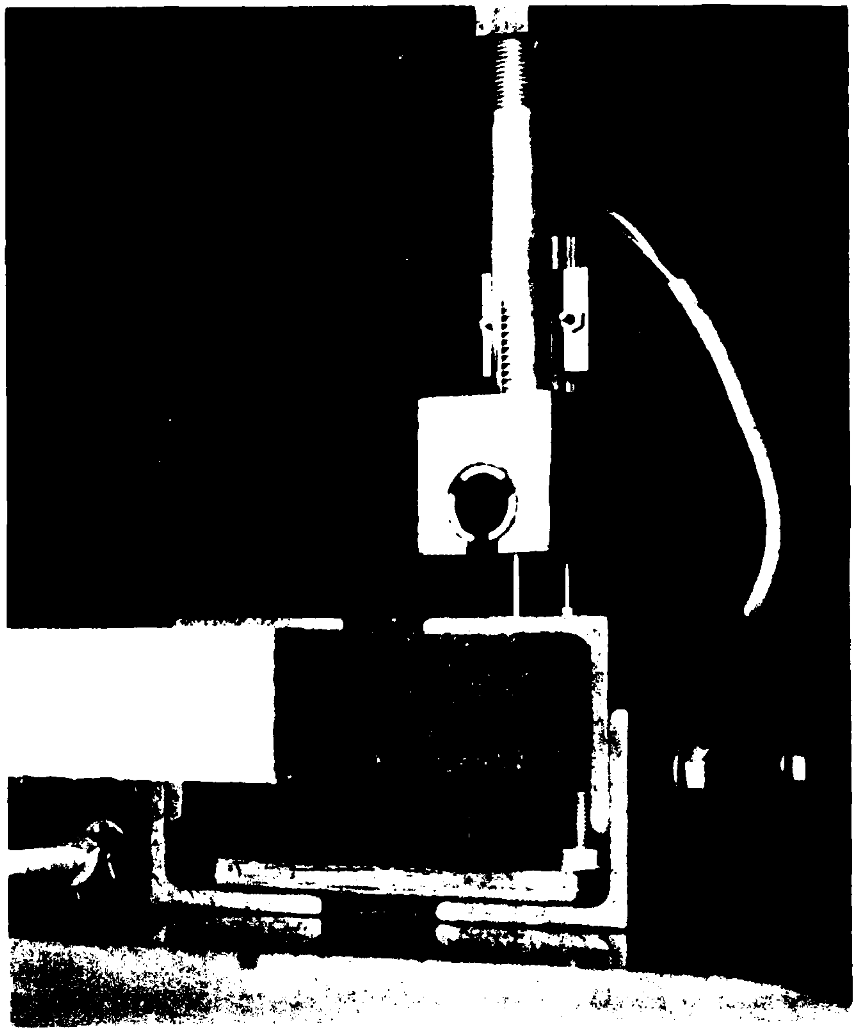

Figure 1.—Nail and staple withdrawal test.

(M 145 523)

A block was cut from each specimen after testing for determination of specific gravity and moisture content.

Lateral Nail Resistance Tests

Two wood members of the same type of veneers with dimensions of 12 inches long, 3-1/2 inches wide, and approximately 1-1/2 inches thick were used for each lateral resistance test. Tenpenny common wire nails, typically 3 inches long and 0.148 inch in diameter, were driven flush to the surface and perpendicular to the glueline 2 inches from the end of each member. In assembling a test specimen, two pieces of wax paper were placed between the wood members to reduce friction and to provide uniformity from test to test.

The specimens were loaded in tension as shown for the slightly different Phase II test specimen, in figure 2 and the tests conducted at a constant machine head speed of 0.1 inch per minute. The slip between the two members was measured with an LVDT and load-slip curves were

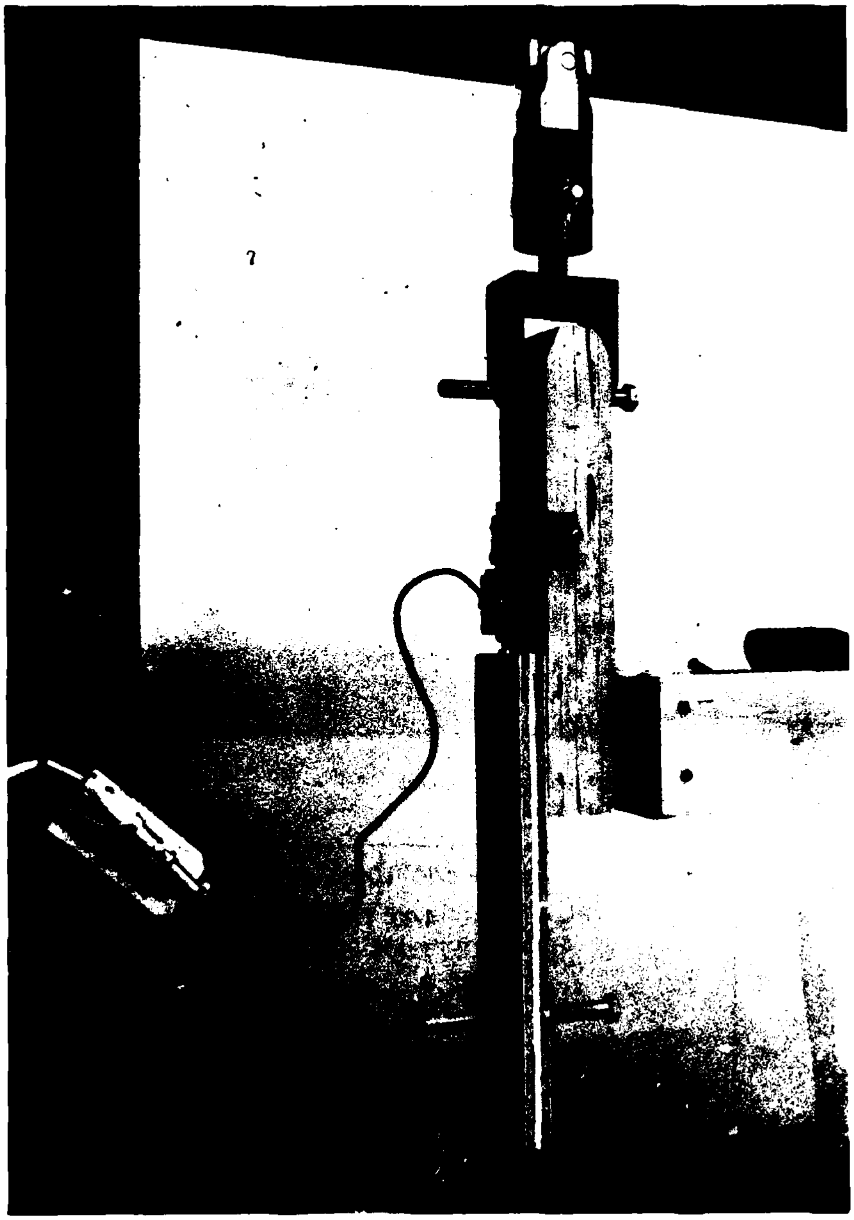

Figure 2.—Laterally loading nailed or stapled joints. The plywood brace kept the specimen in a vertical plane while it was being loaded in tension.

(M 147 025-11)

recorded. Fifteen tests were performed for each material group. Maximum load was also recorded. All specimens were tested immediately after being nailed together. Each nail was used only once.

A block for determination of specific gravity and moisture content was cut from each specimen after testing.

Results and Discussion of Phase I

Lathe Checking

The results of the lathe check measurements are summarized in table 3. The average frequency of checks for the veneer groups ranged from 2.15 to 9.96 checks per inch. The average percent depth (average depth of check divided by thickness of veneer) ranged from 81 to 31 percent; check frequency was inversely proportional to the percent depth of checks. Figure 3 shows a representative sample of lathe checking at each veneer thickness. Figure 4 displays a plot of percent depth versus frequency for each veneer sample evaluated. Frequency (F) and percent depth (D) of checks were related by the equation $D = 94.09 - 6.24F$, with a correlation coefficient (r^2) of 0.93.

Withdrawal Resistance

The results of the nail withdrawal tests are summarized in table 4 and figure 5. Average specific gravity for each group was adjusted to compensate for the specific gravity of the adhesive; theoretical maximum withdrawal load was determined for each material group based on the adjusted specific gravity. The Appendix contains the formulas used to derive the adjusted specific gravities and theoretical loads.

Only Group D (constructed from 1/8-in. tightly checked veneer) had an average maximum withdrawal load (normalized to 1-in. depth of penetration) significantly higher than the rest of the groups at the 90-percent confidence level. This result was probably due to the higher specific gravity of Group D. There was no significant difference between the average maximum withdrawal loads of all other groups at the 90-percent confidence level.

Figure 3.—Typical samples of the degree of lathe checking at each veneer thickness.

(M 145 717-9)

Within each material group (laminated solid sawn, tightly and loosely checked PLV), the means of withdrawal test results showed no consistent trends in relation to the number of laminations, suggesting that veneer thickness had no determinable effect on the withdrawal resistance of nails. Comparison among all material groups showed no detectable trends in relation to the degree of lathe checking, indicating that degree of lathe checking also did not significantly affect the withdrawal resistance of nails.

With the exception of the loosely checked 4/10-inch PLV group, experimentally obtained maximum loads were greater than corresponding theoretical loads. The National Design Specification *(5)* recommends an allowable withdrawal load of 34 pounds per inch of penetration for Douglas-fir under normal loading. Allowable withdrawal loads are taken as being one- sixth the experimental maximum withdrawal load for long-time loading *(10)*. For normal loading, this value is increased by 10 percent.

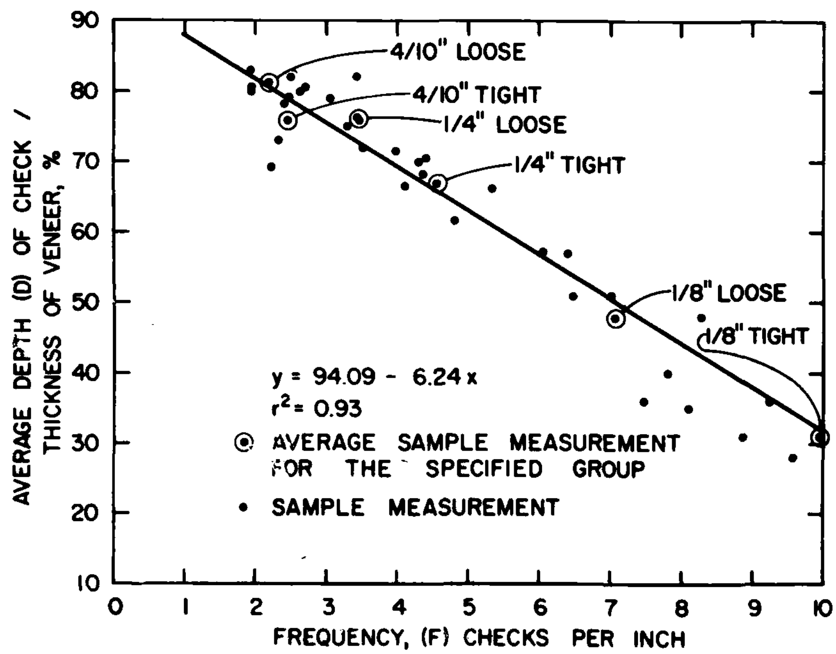

Figure 4.—Plot of frequency (F) versus percent depth (D) of checks for all lathe check samples evaluated. The circled points are the average for each veneer group.

(M 148 600)

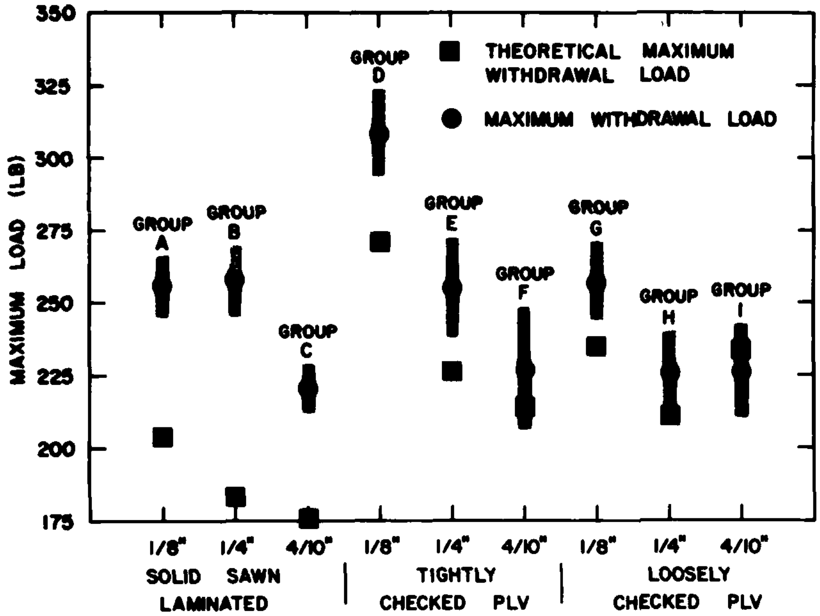

Figure 5.—Results of nail withdrawal tests by material group: average maximum loads (average of 30 tests), corresponding 90 percent confidence intervals, and theoretical maximum loads based on specific gravity adjusted for glue. All loads are normalized to 1-inch depth of penetration.

(M 148 601)

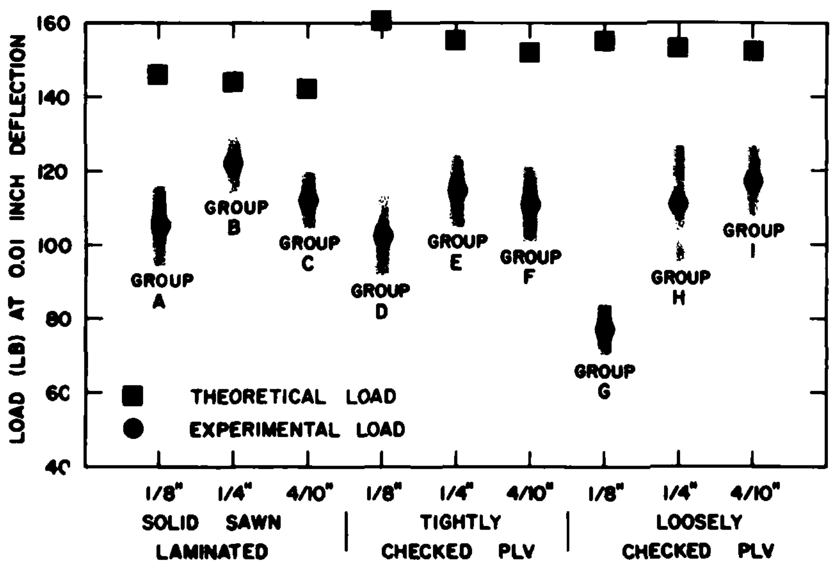

Figure 6.—Results of lateral nail resistance tests by material group: experimental loads (average of 15 tests at 0.01-inch deflection, corresponding 90 percent confidence intervals, and theoretical loads (at 0.01-inch deflection on specific gravity adjusted for glue).

(M 148 602)

If this procedure is applied to this study's experimentally obtained data, all withdrawal loads met the required design values.

Lateral Resistance

The results of the lateral nail resistance tests are summarized in table 5 and figure 6. The formulas used to determine adjusted specific gravities and theoretical loads are given in the Appendix.

All of the average loads at a deflection of 0.01 inch, the assumed proportional limit *(13)*, can be considered equivalent at the 90-percent confidence level, with the exception of Group G (constructed from 1/8-in. loosely checked veneer). Group G had a proportional limit load significantly lower than the other material groups, a difference which may be due to this group's relatively high moisture content.

The lateral resistance of nails does not appear to be significantly affected by changes in veneer thickness or by the degree of lathe checking; comparing the PLV groups to the solid sawn constructions yielded equivalent results. However, the test results for the solid sawn constructions and both PLV groups averaged 70 percent of theoretical values. Although theoretical lateral loads are based on the performance of solid sawn wood, the authors felt that the solid sawn laminated constructions should perform comparably to solid wood. Given this assumption, the test results were indicative of equivalent performance between solid wood and PLV.

The National Design Specifications *(5)* recommend an allowable lateral load of 87 pounds for normal loading and the particular penetration depth used for these tests. Allowable loads for lateral loading are determined by applying a reduction factor of 1.6 to the proportional limit load for longtime loading *(10)*. For normal loading this value is increased by 10 percent. When this increased value was applied to the test data obtained, all results averaged approximately 80 percent of the required design value.

PHASE II

This phase of the study evaluated the joint strength of common fasteners in PLV. Four types of fasteners were tested in PLV constructed from 4/10- and 3/16-inch veneer and from solid wood. These veneer thicknesses represent the thickest produceable and the thickest commercially produced, respectively. The following fastener tests were performed:

1. Staples
   a. Withdrawal
   b. Lateral resistance
2. Bolts
   a. Compression bearing parallel to the wood grain
   b. Compression bearing perpendicular to the wood grain
3. Split-ring timber connectors
   a. Compression bearing parallel to the wood grain
   b. Compression bearing perpendicular to the wood grain
4. Toothed truss plate connectors in tension

Material and Specimen Preparation

The material used for this phase was Coast Douglas-fir from the same geographical location as that used for Phase I. Most of the test material had no knots; a few knots less than 1 inch in diameter were allowed.

The parallel laminated veneer was fabricated using the same procedures as for the 4/10- and 1/4-inch veneer constructions from Phase I. Lathe settings were set to achieve the best quality of veneer at 4/10- and 3/16-inch thicknesses. All material was randomized before laminating. When more than six plies were required for a single construction, the laminating process took place in steps. Five or six plies were laminated in each step to units already glued until the required specimen thickness was obtained. As many as 17 plies were laminated together by this step process.

The solid sawn lumber was kiln-dried to approximately 12 percent moisture content.

Three-quarter-inch, Group 1, grade A- C exterior plywood was purchased for the lateral staple resistance tests.

After material preparations, all specimens were stored at 80° F, 65 percent relative humidity until testing time.

Experimental Procedures

The testing procedures followed those outlined in ASTM D 1761 *(1)*. A block was cut from each member of the test specimens after testing for determination of specific gravity and moisture content.

Staples

Galvanized, 16 gage, plain wire staples 2 inches long with a 7/16-inch crown, were used for all testing. These staples had an adhesive coating which covered 1 inch of the ends. The tests were performed in the same manner as the withdrawal and lateral nail resistance tests of Phase I. Each staple was used only once.

Withdrawal test.—Staples were driven perpendicular to the gluelines with a pneumatic stapler to a depth of approximately 1 inch, a depth which allowed them to be grasped for pulling. The pressure required for 1-inch penetration was approximately 34 pounds per square inch for the solid wood and 42 pounds per square inch for the PLV. The staples were withdrawn at a constant machine head speed of 0.1 inch per minute. Thirty-two tests were performed on each material group. The maximum withdrawal load and depth of staple penetration was recorded for each test.

Lateral resistance test.—Three-quarter-inch plywood was stapled to PLV and solid wood members 3 inches wide and approximately 2 inches thick. The staples were driven flush to the surface perpendicular to the gluelines and 2 inches from the end of each member by a pneumatic stapler using 83 pounds per square inch pressure. The staple crown was perpendicular to the grain direction.

The specimens were loaded as shown in figure 2 and tests conducted at a constant machine head speed of 0.1 inch per minute. The slip between the two members was measured with an LVDT and a load-slip curve automatically recorded. Maximum load was also recorded. Twenty of these tests were performed on each material group.

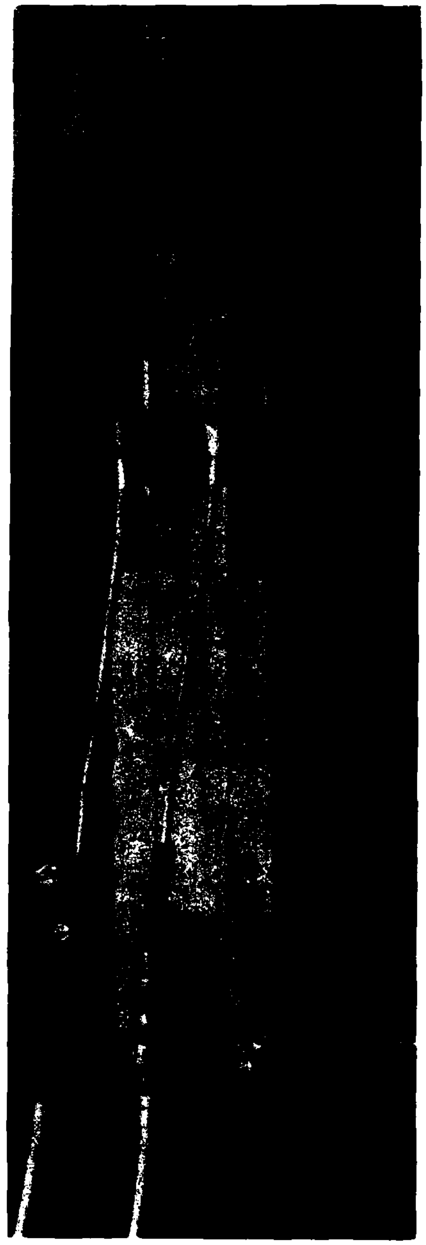

Figure 7.—Loading bolts parallel to the wood grain with average maximum withdrawal load as percent of solid wood load and theoretical maximum withdrawal load as percent of experimental load.

(M 147 024-1)

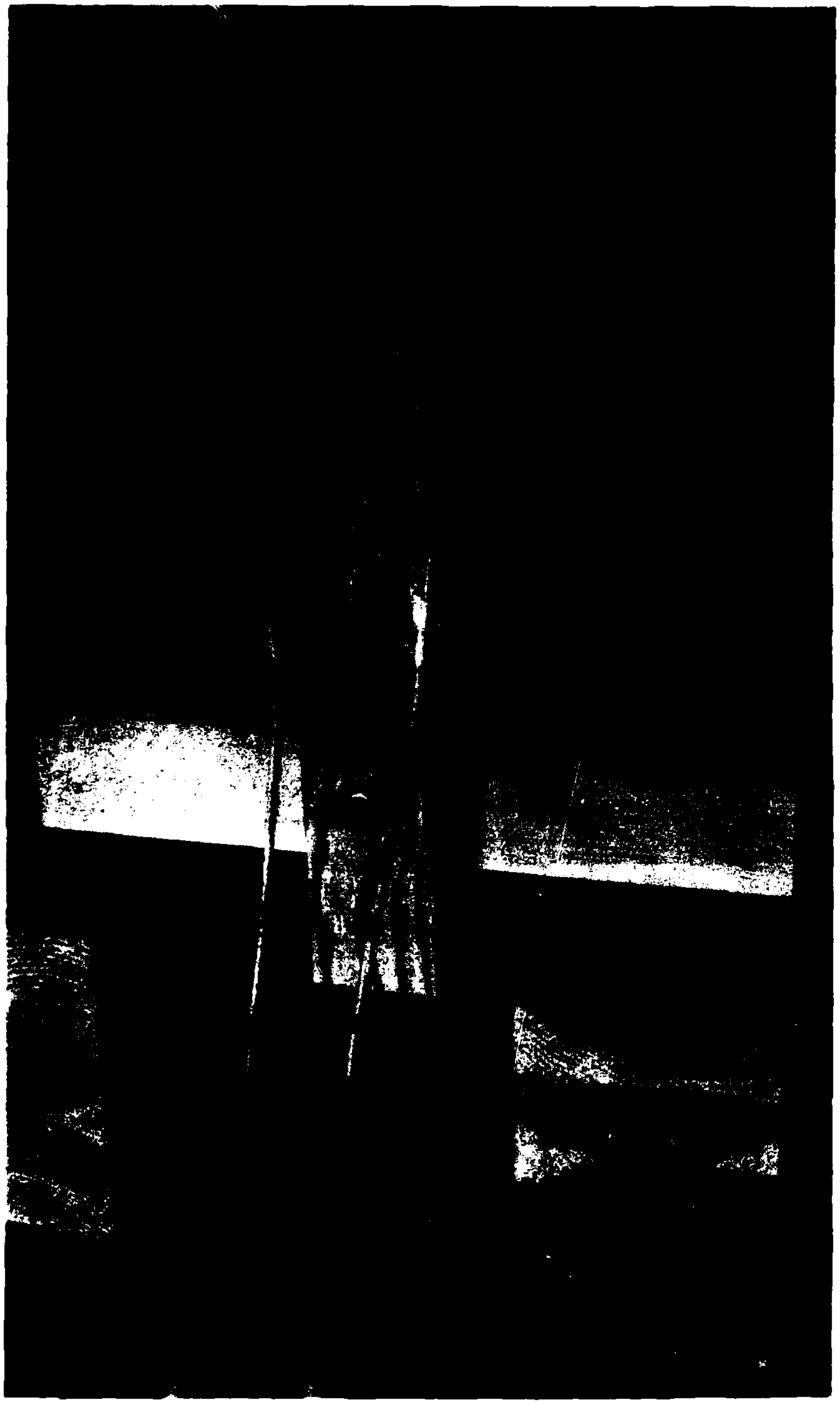

Figure 8.—Loading bolts perpendicular to the wood grain with average load as percent of solid wood load and theoretical load as percent of experimental load.

(M 147 025-9)

Bolts

For this series of tests three-member wood joints were fastened with 1/2-inch-diameter bolts. The center members were approximately 3 by 2 by 18 inches while the side members were 3.0 by 1.2 by 18.0 inches. Compression tests were conducted on joints loaded parallel and perpendicular to the grain of the wood. For loading parallel to the grain of the wood, the bolt hole was centered at 4-1/2 inches from the end of each member of a test specimen (fig. 7). For loading perpendicular to the grain of the wood, the center of the bolt hole on the center members was located 2 inches from the bottom edge and 9 inches from the end of each center member. The bolt holes for the side members were centered at 4-1/2 inches from the end of each side member (fig. 8). The distance between the supports was 9 inches. These configurations meet the required design standards in regard to end and edge distances as specified by the National Design Specification *(5)*.

All bolt holes were 17/32-inch in diameter and care was taken to keep them smooth and uniform. A heavy round washer was placed between the wood side member and the bolt head, and between the wood side member and the nut. Abutting faces of joint members were brought into normally installed contact, the nut backed off, and then retightened to "finger tightness".

Fifteen tests were performed for loading parallel and 14 tests for loading perpendicular to the grain of the wood on each material group. The tests were conducted at a constant machine head speed of approximately 0.035 inch per minute until 0.1-inch deflection was reached. The speed was then increased to 0.1 inch per minute for parallel loading and 0.075 inch per minute for perpendicular loading until maximum load was reached. If maximum load was not reached before 0.6-inch deflection, this point was taken as maximum load; at this point large deformations are accompanied by only small changes in load. Two LVDT's were used to measure the slip of each side member with respect to the center member. Load-slip curves and maximum load were recorded for each test.

Split-Ring Timber Connectors

The tests for split-ring connectors were similar to those conducted for bolts. Test specimens consisting of three-member wood joints were connected with two 4-inch split-ring connectors and a 3/4-inch bolt. The center members were 6.0 by 3.2 by 18.0 inches and the side members 6.0 by 2.0 by 18.0 inches. Compression tests were conducted on joints loaded parallel and perpendicular to the grain of the wood. For loading parallel to the grain of the wood, the connectors and bolt were centered at 7 inches from one end of each member (fig. 9). For loading perpendicular to the grain of the wood, the connectors and bolt were centered at midspan of each member and equidistant from each support. The distance between the supports was 14 inches for perpendicular loading (fig. 10). The connectors were fitted into precut grooves in the center and side members and the bolts assembled as described in the procedure for bolt testing. The bolt holes were 13/16-inch in diameter.

Fifteen tests for loading parallel and 15 tests for loading perpendicular to the grain of the wood were performed on each material group. The tests were conducted at a constant machine head speed of approximately 0.035 inch per minute until 0.1-inch deflection was reached. The speed was then increased to 0.075 inch per minute until maximum load or 0.6-inch deflection was reached. Two LVDT's measured the slip of each side member with respect to the center member. Load-slip curves and maximum load were recorded.

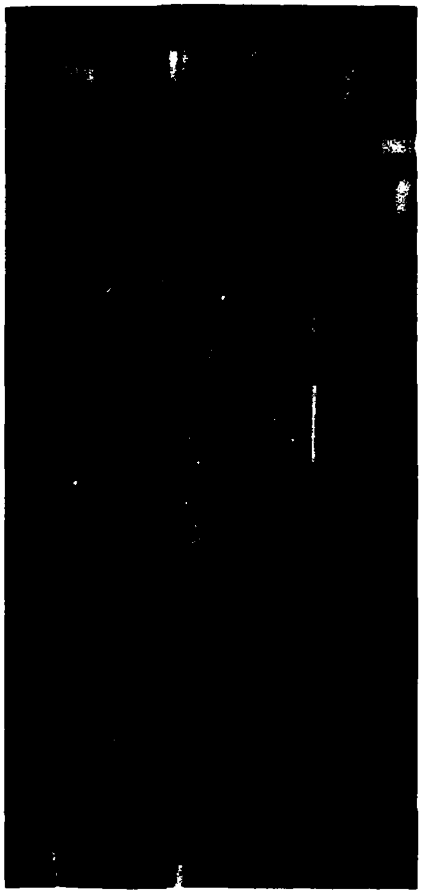

Figure 9.—Loading split-ring connectors parallel to the wood grain.

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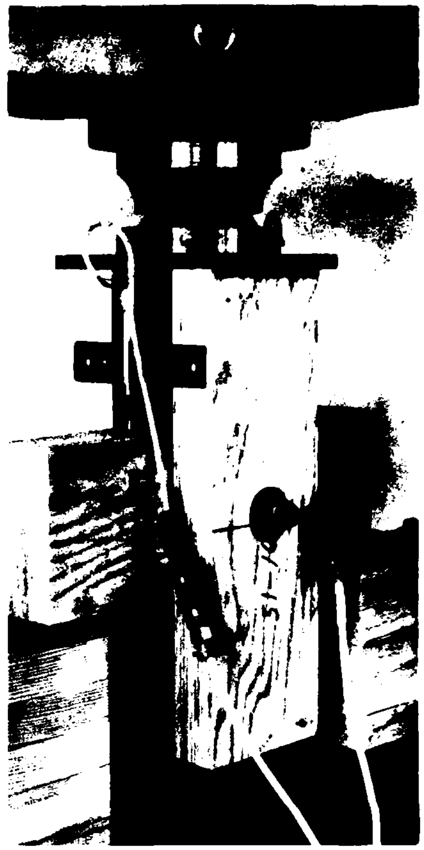

Figure 10.—Loading split-ring connectors perpendicular to the wood grain.

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Toothed Truss Plate

Specimens consisting of two PLV or solid wood members were symmetrically connected end-to-end by two toothed truss plates. Each member was approximately 3.0 by 2.0 by 12.0 inches. The toothed plates were 3 by 6 inches with approximately eight teeth per square inch that were 3/8 inch long. The plates covered the entire width of the wood members. The wood members were tightly butted before the plates were attached. The specimens were loaded in tension as shown in figure 11 and tests conducted at a constant machine head speed of 0.035 inch per minute. Two LVDT's on each side of the specimen measured the deflection between the two members and load-deflection curves recorded. Maximum load was also recorded for all 15 tests performed on each material group.

Results of Phase II

Staples

The results of the staple withdrawal and lateral staple resistance tests are summarized in tables 6 and 7, respectively. The average specific gravities for the PLV products have been adjusted to compensate for the specific gravity of the adhesive. Theoretical loads *(8,9)* were determined for each material group based on the adjusted specific gravities. The average maximum loads and corresponding 90 percent confidence intervals are shown in figure 12 as a percentage of the solid wood loads. Theoretical loads are given in the tables and figures as a percentage of the corresponding experimental loads. The Appendix contains those formulas used to derive the adjusted specific gravities and theoretical loads. Design loads are not given for staples in the National Design Specification *(5)*.

Withdrawal resistance.—As shown in table 6 and figure 12, the maximum withdrawal loads (per inch of penetration) for solid wood and PLV were much higher than theoretically expected. Those results suggest that theoretical methods did not accurately predict the maximum withdrawal load for the staples used in this test program. This discrepancy may be due to the adhesive coating on the staples. The normalized withdrawal

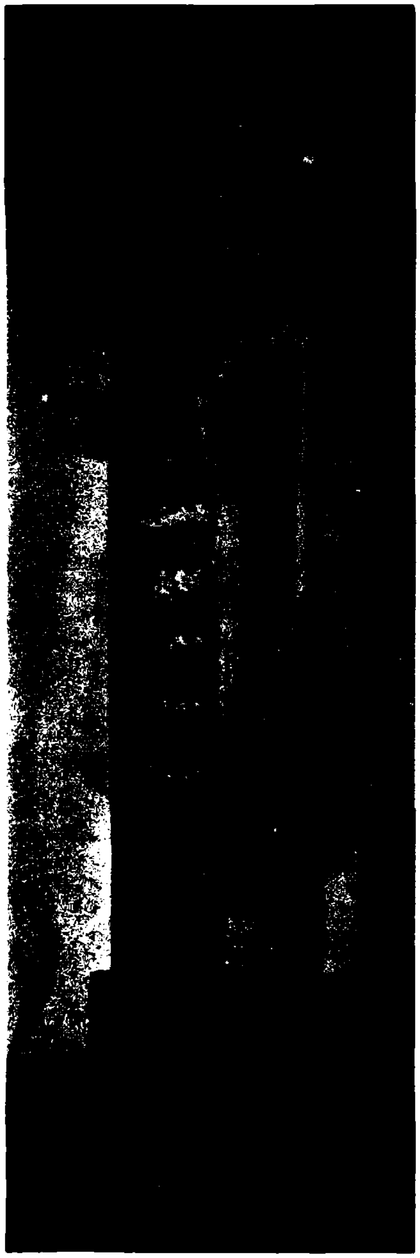

Figure 11.—Tension test on toothed truss plates.

(M 147 024-11)

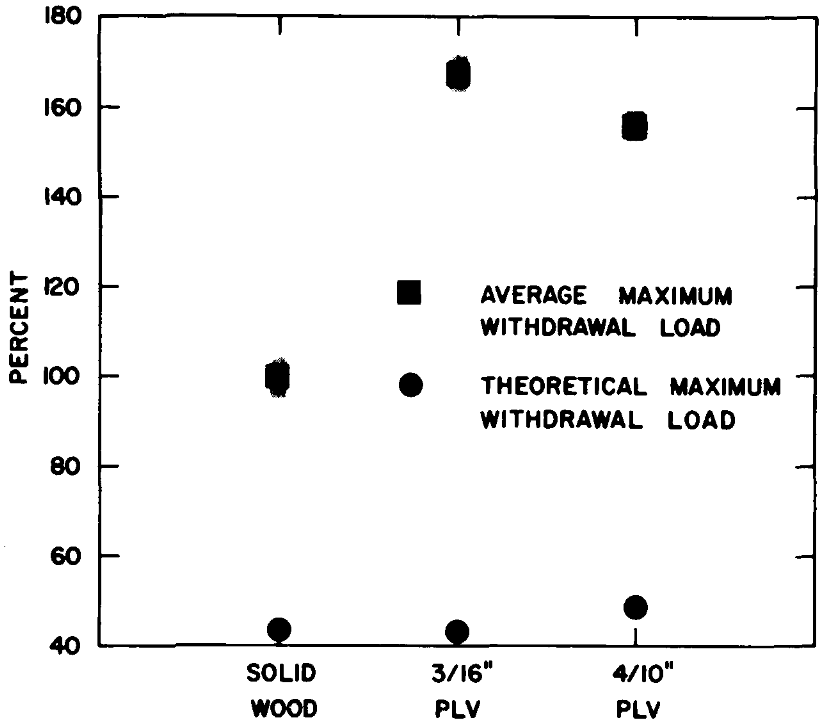

Figure 12.—Results of staple withdrawal tests: average maximum loads and corresponding 90 percent confidence intervals given as percent of maximum load for solid wood. Theoretical loads given as percent of corresponding experimental load for each material group. All loads were normalized to 1-inch depth of penetration.

(M 148 603)

loads for PLV (both 3/16 in. and 4/10 in.) were approximately 60 percent higher than those for solid wood. An analysis of variance at the 90 percent confidence level showed that the normalized withdrawal loads for each material group were significantly different. The coefficients of variation (COV) for the 4/10- and 3/16-inch PLV at the maximum withdrawal load were about one-half of that for solid wood.

It was observed during testing that as the number of material layers increased, the variation in depth of staple penetration also increased. Solid wood showed the least variation and 3/16-inch PLV the most.

Lateral resistance.—For the lateral resistance tests, loads were evaluated at 0.009-inch deflection. This point has been determined through lateral-nailed joint testing as the approximate proportional limit for Douglas-fir subjected to cyclic loading *(13)*. Cyclic loading was not employed in this study and a true proportional limit was not apparent from the tests. However, the proportional limit was assumed to be at 0.009-inch deflection.

At the 90-percent confidence level there is no significant difference between the proportional limit loads for the solid wood and PLV products (fig. 13). The average experimental loads for all material groups are approximately 35 percent higher than theoretical loads. These results indicate that theoretical lateral loads at the proportional limit did not accurately predict the staple loads for the staples used in this test program.

At maximum load there was no significant difference between the 3/16- and 4/10-inch PLV at the 90-percent confidence level. The maximum loads for solid wood averaged approximately 15 percent lower than for the 3/16- and 4/10-inch PLV. Methods for determining theoretical maximum loads for lateral resistance tests have not been derived.

The mode of failure for all tests results was pull-out. The COV's were higher for the PLV products than for solid wood at both the proportional limits and at maximum loads. At proportional limit and maximum loads the COV's averaged 16 percent for 3/16- and 4/10-inch PLV and approximately 9 percent for solid wood.

Bolts

The bearing strength properties for bolts loaded parallel and perpendicular to the wood grain are summarized in table 8. Discussion of the results of the bolt bearing tests is based on the proportional limit load since it forms the base for design loads parallel and perpendicular to the wood grain. Figure 14 shows the proportional limit loads as a percentage of the corresponding solid wood loads. This figure also shows the expected experimental loads at the proportional limit, as converted from the design loads given in the National Design Specifications *(5)* (see Appendix for conversions).

For bearing parallel to the grain of the wood, the PLV loads were approximately 15 percent higher than the solid wood loads at the proportional limit. However, the loads at the proportional limit for all three material groups were significantly lower than the design loads predicted.

For loading perpendicular to the grain of the wood, only the 3/16-inch PLV material averaged higher than the expected test loads (converted from National Design Specifications design loads). The average proportional limit load for 3/16-inch PLV was approximately 70 percent higher than the corresponding experimental load for solid wood. The test specimens generally failed in a combination of horizontal shear and tension perpendicular to grain.

The COV's for the proportional limit loads for loading parallel and perpendicular to the wood grain were highest for solid wood and lowest for 4/10-inch PLV.

Split-Ring Timber Connectors

The results of the tests for split-ring timber connectors are summarized in table 9. All loads are for two 4-inch connectors and one 3/4-inch bolt in double shear.

For loading the connectors parallel to grain, design loads are derived

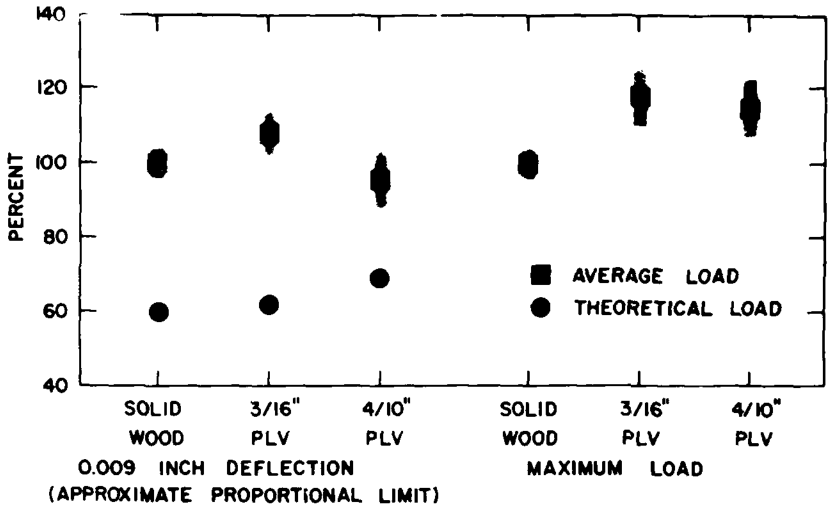

Figure 13.—Results of lateral staple resistance tests: experimental loads and corresponding 90 percent confidence interval given as percent of corresponding solid wood load. Theoretical loads for 0.009-inch deflection given as percent of corresponding experimental loads.

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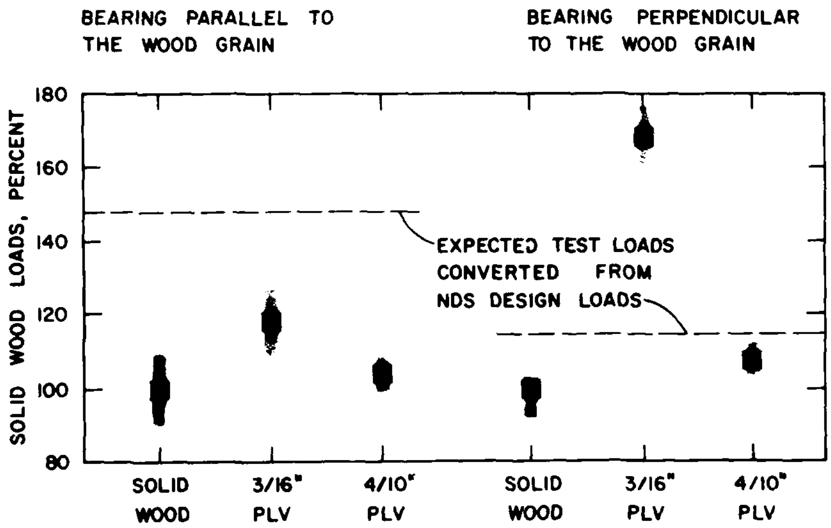

Figure 14.—Results of tests on bolts bearing parallel and perpendicular to the wood grain: average loads and corresponding 90 percent confidence intervals at the proportional limit. The dashed lines indicate expected proportional limit loads which were converted from NDS design loads.

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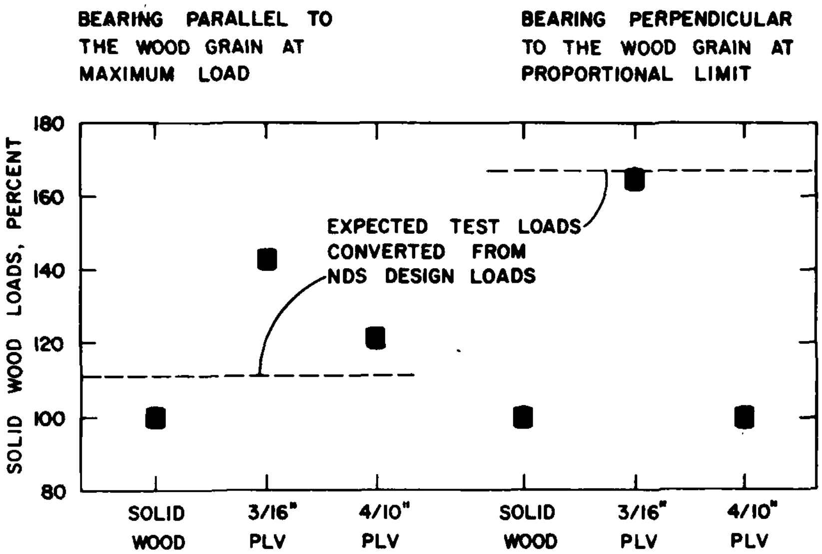

Figure 15.—Results of tests on split-ring connectors bearing parallel and perpendicular to the wood grain: average loads and corresponding 90 percent confidence intervals for the loads specified. The dashed lines indicate expected test loads which were converted from NDS design loads.

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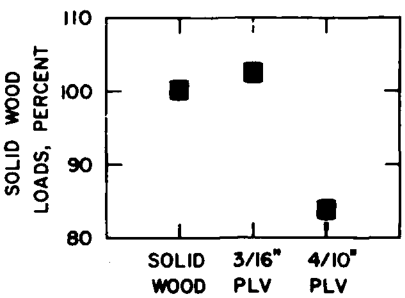

Figure 16.—Results of truss plate tension tests: average maximum loads and corresponding 90 percent confidence intervals given as percent of the maximum load for solid wood.

(M 148 607)

from the maximum load. Figure 15 shows the maximum loads for the PLV products as a percentage of the solid wood load. Also shown is the expected maximum load which was converted from National Design Specifications design loads. The solid wood load averaged 11 percent below the expected maximum load. The 3/16- and 4/10-inch PLV averaged 43 and 21 percent higher, respectively, than did the solid wood maximum load. For parallel-to-grain loading, the COV's for all of the maximum loads were under 7 percent. The failure was usually shearing parallel to grain of the wood inside the connectors.

For split-ring connectors loaded perpendicular to the grain of the wood, design loads are derived from the proportional limit load. In figure 15 the proportional limit loads for the PLV products are given as a percentage of the solid wood load. The proportional limit loads for the 3/16-inch PLV averaged 65 percent higher than the corresponding solid wood load, and the 4/10-inch PLV was equivalent to the average load for solid wood at the 90 percent confidence level. Figure 15 also shows the expected proportional limit load which was converted from National Design Specifications design loads. Only the 3/16-inch PLV came near meeting the required design load. The solid wood and 4/10-inch PLV are 60 percent of the required design load. The COV's for the proportional limit loads under perpendicular loading were all approximately 13 percent. The mode of failure was shearing of the wood inside the connectors perpendicular to the direction of the grain.

Truss Plates

The results of the truss plate tension tests are summarized in table 10 and figure 16. In figure 16 the maximum loads for the PLV products are given as a percentage of the solid wood loads. There was no significant difference between the average maximum loads for solid wood and 3/16-inch PLV at the 90-percent confidence level. The 4/10-inch PLV averaged 84 percent of the solid wood maximum load. The COV's for all material groups were less than 9 percent.

Generally, if the load exceeded 7,000 pounds there was some tearing of the plate. Approximately two-thirds of the tests in solid wood and 3/16-inch PLV exhibited some failure of the truss plates. Only 2 out of 15 tests had partial failure of the truss plates for the 4/10-inch PLV.

Summary and Discussion of Results

A summary of the Phase II results is given in table 11 as a percentage of the corresponding solid wood test values.

Effect of Veneer Thickness[3]

Throughout the entire test program the PLV constructed from 3/16-inch veneer consistently performed better than 4/10-inch PLV and solid wood. The results of testing these two types of PLV materials were statistically equivalent at a 90 percent confidence level for the bolt bearing parallel test

[3] The comparisons given between groups of materials for a given test are based, if possible, on the results from which design loads are determined: at the proportional limit for bolts loaded parallel and perpendicular to grain, for split rings loaded perpendicular to grain, and for laterally loaded staples; at the maximum load for staple withdrawal, for truss plates and for split rings loaded parallel to grain.

only. The 3/16-inch PLV results were higher than solid wood values: by approximately 70 percent for bolts bearing perpendicular to grain, by 63 percent for staple withdrawal, by 65 percent for split rings bearing perpendicular to grain, by 43 percent for split rings bearing parallel to grain, by 20 percent for bolts bearing parallel to grain, and by less than 10 percent for the laterally loaded staples and truss plate tests. The increased load-carrying capabilities of the 3/16-inch PLV could be due, in part, to better load sharing between the plies; the effect of glue on the mechanical properties of wood is possibly more significant for thinner laminations (*6*). The results of the tests on the split rings and bolts bearing perpendicular to grain (values that were 65 to 70 pct higher than solid wood) are somewhat surprising since the failure plane is along the lathe checks and is usually considered weak relative to solid wood (*4*).

The PLV constructed from 4/10-inch veneer performed at least as well as solid wood (within 5 pct or better) for all fasteners tested except truss plates. The results for the 4/10-inch PLV were higher than those for solid wood by approximately 56 percent for staple withdrawal, by 21 percent for split rings bearing parallel to grain, by 13 percent for bolts bearing parallel to grain, and by 8 percent for bolts bearing perpendicular to grain. The 4/10-inch PLV results were approximately equivalent to the solid wood results for tests of lateral staples, for tests on split rings bearing perpendicular to grain, and for 84 percent of solid wood results for the toothed truss plate tests. For the toothed truss plate tests, the reduced load-carrying capability of the 4/10-inch PLV could be due to the crushing noted when the truss plates were being pressed into the joint. This crushing was detected only for the 4/10-inch PLV and is most likely caused by more severe lathe checking of this material, a condition which, in turn, could have reduced its compressive strength perpendicular to grain.

Variability of Results

The COV's of the results (table II) from tests on bolts, split rings, and truss plates were, in most cases, slightly lower for the 3/16- and 4/10-inch PLV than for solid wood. There did not appear to be a significant difference between the COV's of the two PLV's.

The COV's for the staple tests ranged from 7 to 16 percent for the loads that were evaluated and did not display any consistent trends.

Effect of Moisture Content

It is recognized that the properties of wood can change considerably with changes in moisture content. Unfortunately, the different groups of material in this study were not conditioned to equivalent moisture contents and, thus, the degree to which moisture content influenced the results cannot be readily determined. However, the standard corrections for moisture content may not be applicable since we are generally dealing with proportional limits, not ultimate strengths. Also, the properties which influence the various fastener characteristics generally cannot be isolated. The solid wood, the 3/16-inch PLV, and the 4/10-inch PLV had average moisture contents of approximately 12.1, 8.5, and 9.8 percent, respectively. The general trend in the test results appears to follow the notion that as the moisture content decreases, the performance increases.

Effect of Specific Gravity

Specific gravity is another factor which may have significantly affected the results of this study. Although all of the wood used for this study was from the same geographical location and randomization techniques were used, the specific gravity of the 4/10- and 3/16-inch PLV averaged 27 and 22 percent higher, respectively, than did the average specific gravity for the solid Douglas-fir. It appears that PLV has a higher specific gravity due to the adhesive and a slight densification of the wood during the drying and laminating processes.

Conclusions for Phase I and II

The important conclusions of this study, limited to essentially clear material from Douglas-fir, were:

1. Assuming equivalent performance between the solid sawn-laminated construction of Phase I and solid wood, there is no reduction in the withdrawal or lateral loading of nails in PLV when compared to solid wood.

2. Veneer thickness and degree of lathe checking have no appreciable effect on the withdrawal or lateral resistance of nails in PLV.

3. The 3/16-inch PLV performed better than solid wood for all fasteners tested in Phase II (i.e., staples, bolts, split rings, and truss plates). This performance may be due in part to the combined effects of lower moisture content and higher specific gravity, but may also be due to better load sharing between laminations and the effect of glue on the mechanical properties of PLV with thinner laminations.

4. Although the lower moisture content and higher specific gravity of 4/10-inch PLV may have accounted for its performing better than solid wood, the authors felt that the 4/10-inch PLV would perform at least as well as solid wood at identical moisture content and densities for all fasteners tested in Phase II, except toothed truss plates. The lathe checking in PLV from thickly peeled veneer appears to reduce its load-carrying capability for toothed truss plates.

5. The 3/16-inch PLV performed significantly better than the 4/10-inch PLV for all tests in Phase II except those for staples and bolts bearing parallel to grain, a performance which suggests that veneer thickness does affect the loading capacity of some fasteners in PLV. This effect is probably due to the reasons given in the third conclusion.

6. The variation in test results for the bolts, split rings, and truss plates was, generally, slightly lower for PLV than for solid wood. The variation in test results for the nails and staples was erratic.

7. No severe reduction in the load-carrying characteristics of fasteners in PLV relative to those of solid wood was detected, with the exception of 4/10-inch PLV with truss plates as previously reported (*3*).

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Table 1.—Identification of material groups for Phase I[1]

Type of plies	Ply thickness	Number of plies	Material group label
	In.		
Laminated	1/8	12	A
solid-sawn	1/4	6	B
Douglas-fir	4/10	4	C
Tightly	1/8	12	D
checked	1/4	6	E
veneer	4/10	4	F
Loosely	1/8	12	G
checked	1/4	6	H
veneer	4/10	4	I

[1] Material laminated to produce 1-1/2-in. stock.

Table 2.—Lathe settings used to achieve varying degrees of lathe checking and veneer thickness

Desired dry thickness	Degree of checking (tight vs. loose)	Lathe feed	Compression	Nose bar gap	Nose bar lead
In.		In./rev	Pct	In.	In.
1/8	Tight	0.1378	20	0.110	0.030
1/8	Loose	.1378	5	.131	.030
1/4	Tight	.2750	15	.234	.040
1/4	Loose	.2750	5	.261	.040
4/10	Tight	.4388	10	.395	.060
4/10	Loose	.4388	3	.425	.060

Table 3.—Summary of data for lathe check measurements of Douglas-fir veneer

Veneer group			
Thickness of veneer	Degree of checking (tight vs. loose)	Average percent depth (Average depth check divided by thickness of veneer)	Frequency of checks
In.			Checks/in.
4/10	Loose	81	[1]2.15
4/10	Tight	76	[1]2.45
1/4	Loose	76	[2]3.44
1/4	Tight	67	[2]4.55
1/8	Loose	48	[3]7.06
1/8	Tight	31	[3]9.96

[1] Values are the average of five 13-1/2-in.-wide samples.
[2] Values are the average of six 13-1/2-in.-wide samples.
[3] Values are the average of seven 13-1/2-in.-wide samples.

Table 4.—Summary of data for direct withdrawal of eightpenny common nails[1]

Material group	Material group label	Construction: Thickness of plies	Construction: Number of plies	Moisture content	Specific gravity[2]: Before adjustment for adhesive	Specific gravity[2]: After adjustment for adhesive	Maximum withdrawal load per 1-inch penetration	Theoretical maximum withdrawal load[3]
		In.		Pct			Lb	Lb
Laminated solid-sawn	A	1/8	12	12.5	0.548	0.524	256	204
	B	1/4	6	12.4	.513	.501	258	183
	C	4/10	4	12.8	.501	.494	221	176
Tightly checked PLV	D	1/8	12	13.0	.610	.587	308	271
	E	1/4	6	10.3	.558	.546	255	227
	F	4/10	4	10.9	.541	.534	227	214
Loosely checked PLV	G	1/8	12	14.9	.578	.554	257	235
	H	1/4	6	10.4	.543	.531	226	211
	I	4/10	4	11.1	.558	.552	226	233

[1] Values are the average of 30 tests withdrawn perpendicular to the gluelines.
[2] Specific gravity based on overdry weight and volume at test. Adjustment for the specific gravity is described in the appendix.
[3] Theoretical load based on adjusted specific gravity.

Table 5.—Summary of data for lateral loading of tenpenny common nails[1]

Material group	Material group label	Construction: Thickness of plies	Construction: Number of plies	Average moisture content	Specific gravity[2]: Before adjustment for adhesive	Specific gravity[2]: After adjustment for adhesive	Load at deformation of 0.01 inch	Theoretical load at deformation of 0.01 inch[3]	Average maximum load
		In.		Pct			Lb	Lb	Lb
Laminated solid-sawn	A	1/8	12	15.5	0.529	0.504	105	146	464
	B	1/4	6	13.7	.505	.493	122	144	487
	C	4/10	4	14.8	.494	.487	112	142	447
Tightly checked PLV	D	1/8	12	15.9	.599	.575	102	161	538
	E	1/4	6	10.8	.557	.545	115	155	485
	F	4/10	4	11.3	.540	.533	111	152	396
Loosely checked PLV	G	1/8	12	18.3	.571	.547	77	155	434
	H	1/4	6	11.0	.549	.537	111	153	435
	I	4/10	4	11.9	.539	.533	117	153	402

[1] Values are the average of 15 tests loaded parallel to the wood grain.
[2] Specific gravity based on ovendry weight and volume at test. Adjustment for the specific gravity of glue is described in the appendix.
[3] Theoretical load based on adjusted specific gravity.

Table 6.—Summary of data for direct withdrawal of 16-gage staples[1]

Material group	Specific gravity[2] Before adjustment for adhesive	Specific gravity[2] After adjustment for adhesive	Moisture content	Maximum withdrawal load per inch of penetration	Maximum load theoretical divided by experimental
			Pct	Lb	Pct
Solid wood	0.43	0.43	12.1	282 [3](16)	43
PLV from 3/16-inch veneer	.53	.51	6.8	473 (10)	43
PLV from 4/10-inch veneer	.54	.54	10.0	439 (7)	49

[1] Values are the average of 32 tests withdrawn perpendicular to the glueline.
[2] Specific gravity based on ovendry weight and volume at test. Adjustment for the specific gravity of glue is described in the appendix.
[3] Numbers in parentheses are coefficients of variation in percent.

Table 7.—Summary of data for lateral staple resistance tests[1]

Material group for main member	Specific gravity[2] Main member Before adjustment for adhesive	Specific gravity[2] Main member After adjustment for adhesive	Specific gravity[2] Plywood member	Moisture content Main member	Moisture content Plywood member	Load at 0.009-inch deflection Experimental	Load at 0.009-inch deflection Theoretical	Maximum load
				Pct	Pct	Lb	Pct	Lb
Solid wood	0.42	0.42	0.46	11.9	8.5	80 [3](9)	60	309 (9)
PLV from 3/16-inch veneer	.53	.51	.47	8.1	7.6	86 (16)	62	366 (16)
PLV from 4/10-inch veneer	.55	.54	.47	9.5	8.1	77 (19)	69	356 (16)

[1] Values are the average of 20 tests loaded parallel to the wood grain.
[2] Specific gravity based on ovendry weight and volume at test. The specific gravity of the main member has been adjusted for the specific gravity of the glue according to formulas given in appendix.
[3] Numbers in parentheses are coefficients of variation in percent of the corresponding load.

Table 8.—Strength of 3-member bolted joints with loads bearing parallel and perpendicular to grain[1]

Material group	Direction of loading	Specific gravity[2]	Moisture content	Proportional limit		Maximum load	
				Load	Deflection	Load	Deflection
			Pct	Lb	In.	Lb	In.
Solid wood	Parallel	0.44	11.9	1,780 [3](20)	0.0259 (23)	5,360 (14)	0.537 (21)
	Perpendicular	.44	11.3	1,120 (15)	.0333 (18)	2,490 (11)	.160 (28)
PLV from 3/16-inch veneer	Parallel	.53	8.1	2,130 (16)	.0240 (29)	7,530 (5)	.589 (6)
	Perpendicular	.53	8.4	1,890 (10)	.0319 (21)	5,200 (5)	.451 (17)
PLV from 4/10-inch veneer	Parallel	.55	9.7	2,020 (9)	.0196 (19)	6,060 (7)	.473 (18)
	Perpendicular	.55	9.5	1,210 (8)	.0249 (16)	3,520 (8)	.256 (27)

[1] Values are the average of 15 tests for parallel loading and 14 tests for perpendicular loading with one 1/2-in. bolt in double shear.
[2] Specific gravity based on ovendry weight and volume at test.
[3] Numbers in parentheses are coefficients of variation in percent of the corresponding load or deflection.

Table 9.—Strength of 3-member, split-ring timber connector joints with loads bearing parallel and perpendicular to grain[1]

Material group	Direction of loading	Specific gravity[2]	Moisture content	Proportional limit		Maximum load	
				Load	Deflection	Load	Deflection
			Pct	Lb	In.	Lb	In.
Solid wood	Parallel	0.44	12.3	11,300 [3](11)	0.0257 (15)	30,700 (7)	0.460 (26)
	Perpendicular	.44	12.8	5,930 (15)	.0387 (19)	11,400 (11)	.129 (16)
PLV from 3/16-inch veneer	Parallel	.53	8.7	14,700 (17)	.0208 (21)	43,800 (2)	.496 (16)
	Perpendicular	.54	8.6	9,780 (11)	.0410 (17)	14,800 (5)	.106 (35)
PLV from 4/10-inch veneer	Parallel	.56	10.2	15,100 (12)	.0241 (18)	37,000 (4)	.402 (19)
	Perpendicular	.56	9.9	5,910 (14)	.0249 (23)	11,700 (5)	.092 (15)

[1] Values are the average of 15 tests with two 4-in. split rings and one 3/4-in. bolt in double shear.
[2] Specific gravity based on ovendry weight and volume at test.
[3] Numbers in parentheses are coefficients of variation in percent of the corresponding load or deflection.

Table 10.—Summary of data on tensile test of toothed truss plate joints[1]

Material group	Specific gravity[2]	Moisture content	Maximum load
		Pct	Lb
Solid wood	0.43	12.5	7,120 [3](9)
PLV from 3/16-inch veneer	.54	8.5	7,360 (5)
PLV from 4/10-inch	.56	9.5	5,980 (9)

[1] Values are the average of 15 tests.
[2] Specific gravity based on ovendry weight and volume at test.
[3] Numbers in parentheses are coefficients of variation in percent.

Table 11.—A summary in percent of the Phase II results as a percent of the corresponding solid wood values

	Staples		Bolts loaded		Split rings loaded		Truss plates
	Direct withdrawal	Lateral resistance	Parallel	Perpendicular	Parallel	Perpendicular	
Material group	Maximum load	Load at 0.009-inch	Proportional limit	Proportional limit load	Maximum load	Proportional limit load	Maximum load
	Pct						
Solid wood	100 [1](16)	100 (9)	100 (20)	100 (15)	100 (7)	100 (15)	100 (9)
PLV from 3/16-inch veneer	163 (10)	108 (16)	120 (16)	169 (10)	143 (2)	165 (11)	103 (5)
PLV from 4/10-inch veneer	156 (7)	96 (19)	113 (9)	108 (8)	121 (4)	100 (14)	84 (9)

[1] Numbers in parentheses are coefficients of variation in percent.

Appendix

Procedure for Adjusting Specific Gravity

The true specific gravity of the wood was estimated by adjusting for the specific gravity of the adhesive:

$$G_w = \frac{G_iV_i - G_gV_g}{V_w} \qquad (1)$$

where: G = specific gravity

V = volume,

i = initial values taken at the time of testing,

g = values for adhesive, and

w = values for wood.

An average glueline thickness was estimated to be 0.005 inch and volumes were determined from recorded specimen dimensions. The specific gravity of the phenol resorcinol adhesive was determined to be 1.26. For Phase I the specific gravity for each material group was adjusted for the adhesive and these adjusted specific gravities reported in tables 4 and 5. For Phase II, only the specific gravities of the PLV products used for the staple tests were adjusted for adhesive and are reported in tables 6 and 7.

Theoretical Loads For Nails and Staples

The theoretical maximum withdrawal loads for nails and staples in solid wood are given by the empirical formula from the Wood Handbook *(10)*

$$P = (7850)G^{5/2}DL \qquad (2)$$

where: P = maximum withdrawal load in pounds,

G = specific gravity of wood,

D = diameter of nail or staple leg in inches, and

L = depth of nail or staple penetration in inches.

For staples the load P is doubled to account for each staple leg. For the lateral nail tests of Phase I, the theoretical lateral load up to the proportional limit (0.009 in. for Douglas-fir *(13)*) is approximated by the formula *(11)*:

$$P = \frac{K_O^{3/4}E^{1/4}D^{7/4}S}{6} \qquad (3)$$

where: P = lateral load in pounds,

K_O = elastic bearing constant,

E = modulus of elasticity of the nail or staple in lb/in.^{2},

D = nail or staple leg diameter in inches, and

S = joint slip in inches.

The elastic bearing constant, Ko is 2,144,000 G for these nail tests *(11)*.

For the lateral staple tests of Phase II, the theoretical lateral load is predicted by a more complex variation of the above formula due to dissimilar members in each specimen *(11)*:

$$P = 2\,E^{1/4}I^{1/4}K_O^{3/4}D^{3/4}S\,b_i \qquad (4)$$

For this equation, I is the moment of inertia of the nail cross-section, b is a function of the elastic bearing constants of each member, and the other constants are given above. Details for this equation are given in references 11 and 12, and were followed to obtain the theoretical lateral staple loads.

Converting Design Loads To Expected Test Loads

Bolts

The conversions used to determine the expected proportional limit loads from National Design Specifications (NDS) design loads for bolts are based on Trayer *(9)*.

For bolt bearing parallel and perpendicular to the grain, the NDS allowable design loads were converted to the expected proportional limit loads by multiplying the allowable design loads by the variability and safety factor 2.25.

Split Rings

The conversions used to determine expected test loads from NDS design loads for split rings are based on Scholten *(8)*.

For split rings bearing parallel to grain, the allowable design load given in NDS (for two 4-in. split rings and one 3/4-in. bolt having a net thickness of 2 in. with two faces of the center piece with connectors on same bolt) were used to determine the expected test loads. This design load was multiplied by 4, the "reduction" factor, to give the approximate maximum load.

For split rings bearing perpendicular to grain, two times the allowable design load given in NDS (with the same split ring specifications as for parallel loading) were used to determine the expected proportional limit load. This design load was multiplied by 2, the recommended reduction factor, and divided by 1.1 to obtain long-time loading conditions and the approximate proportional limit load.

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Strength of Fasteners in Parallel-Laminated Veneer, by Joseph Jung and Judy Day, Madison, Wis., FPL, 1981 21p. (USDA For. Serv. Res. Pap. FPL 389)

Phase I of this study shows that the effects of lamina thickness and the degree of lathe checking could not be detected in either nail withdrawal or lateral loading.

In Phase II, PLV from 3/16- and 4/10-inch Douglas-fir shows no severe reduction in fastening strength for bolts, staples, split rings, and truss plates. The only exception is for truss plates on 4/10-inch PLV.

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